Indigenous Carbon Dioxide as a Propellant for Mars Surface Probes

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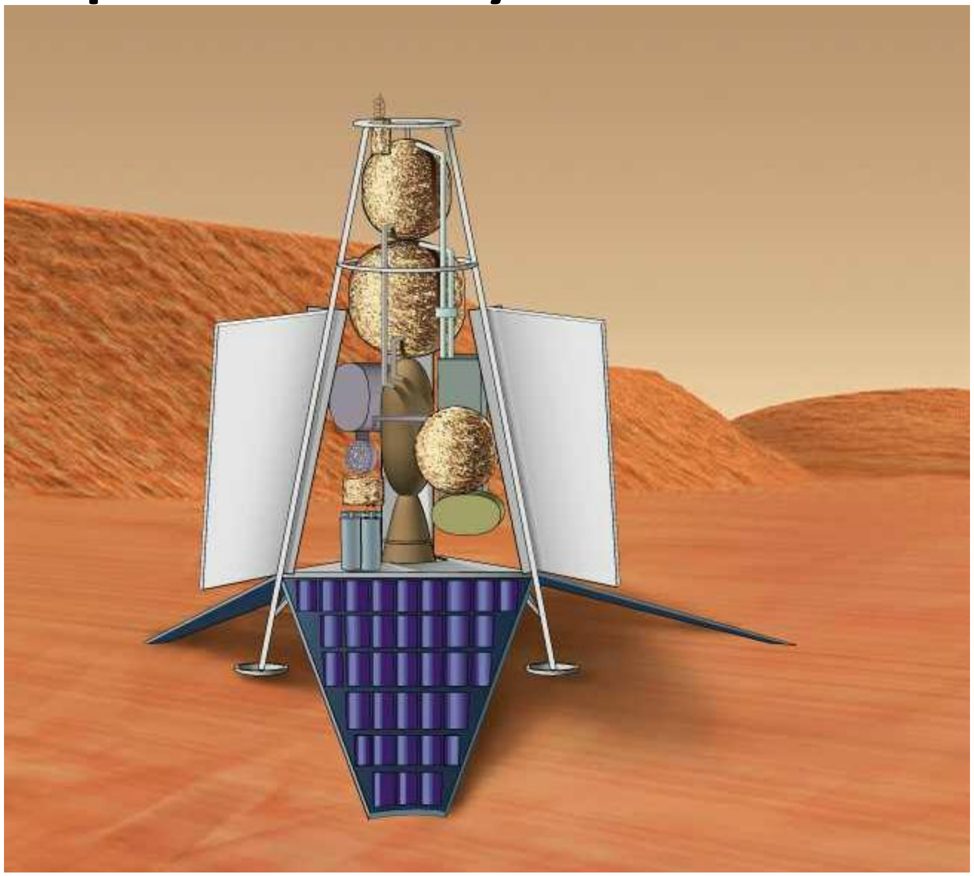
Carbon dioxide propellant has been considered previously

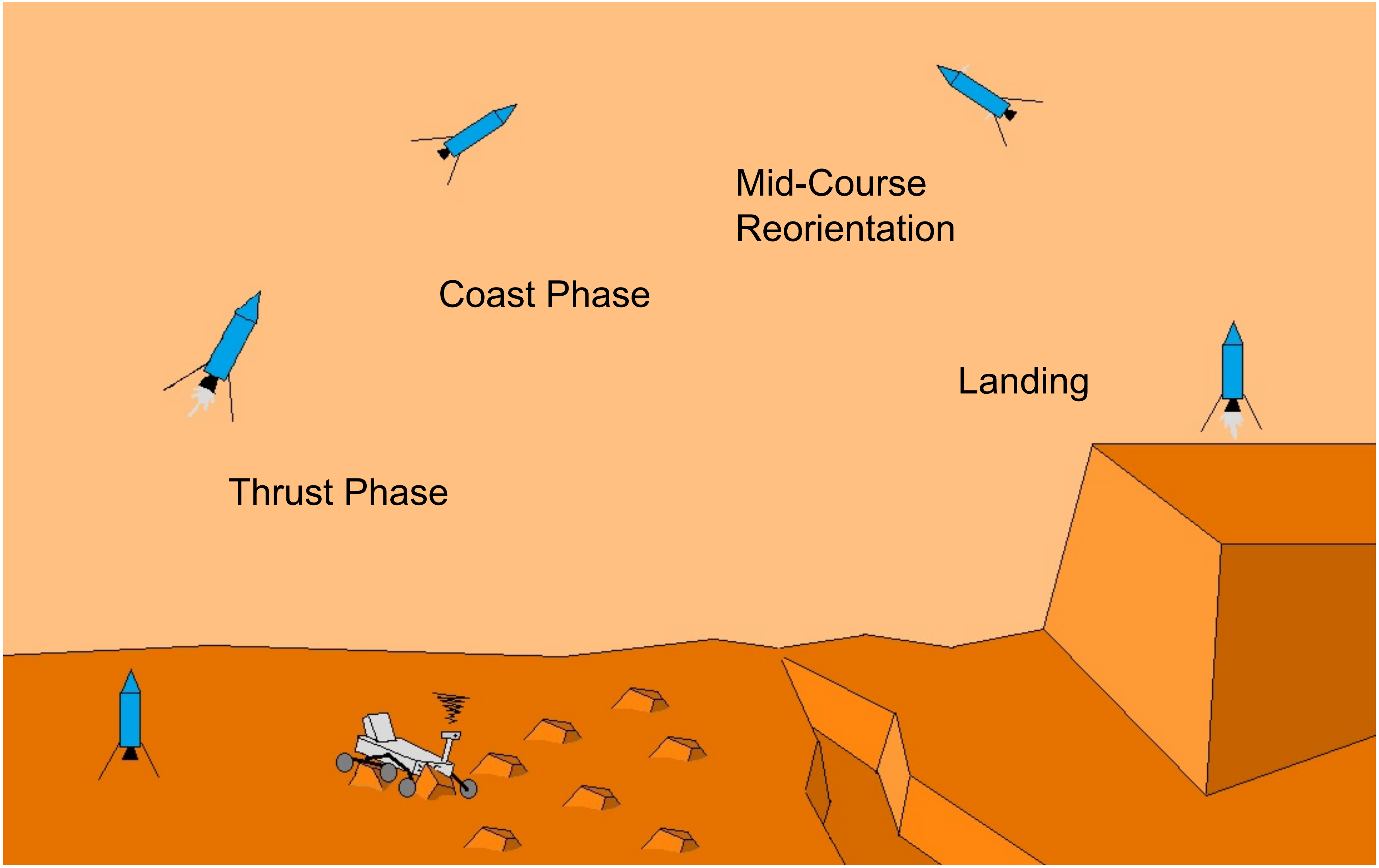
Idaho National Laboratory
Nuclear-powered "Gas hopper"



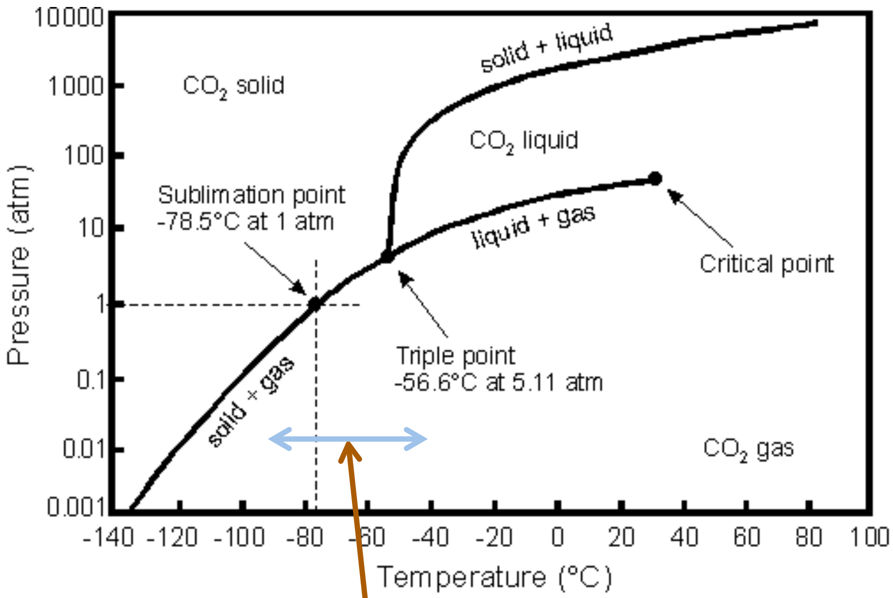
Solar-powered surface probe concept
(G. Landis and D. Linne)

Can solar energy be used to produce dry ice, then convert it to propellant?

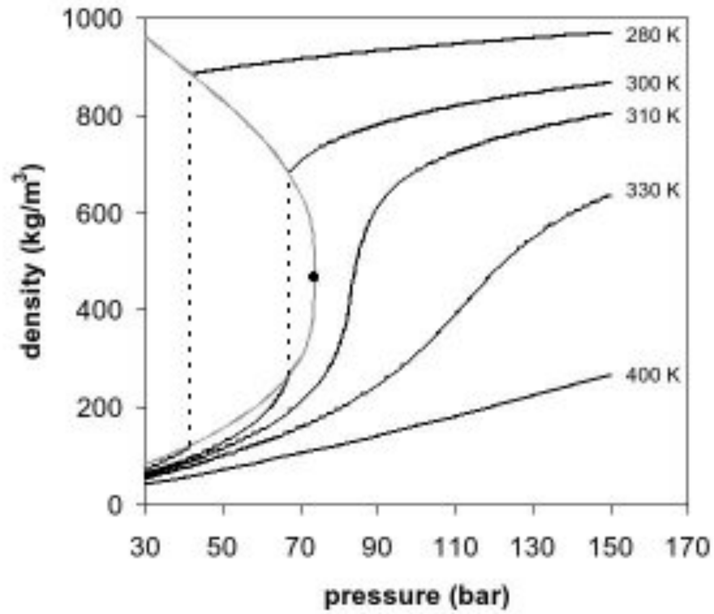
Hopper Mobility



95.32% of the Martian atmosphere



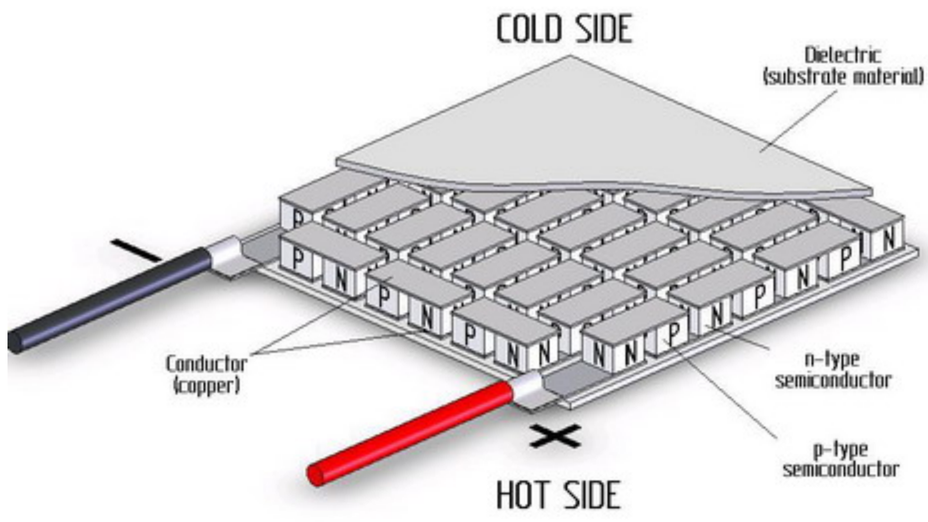
Pressure-Temperature phase diagram for CO_2.



Nominal ambient temperature: 210 K;
50 K diurnal temperature swings are common

Use solar energy to make dry ice at night and rocket propellant during the day. *Is this feasible?*

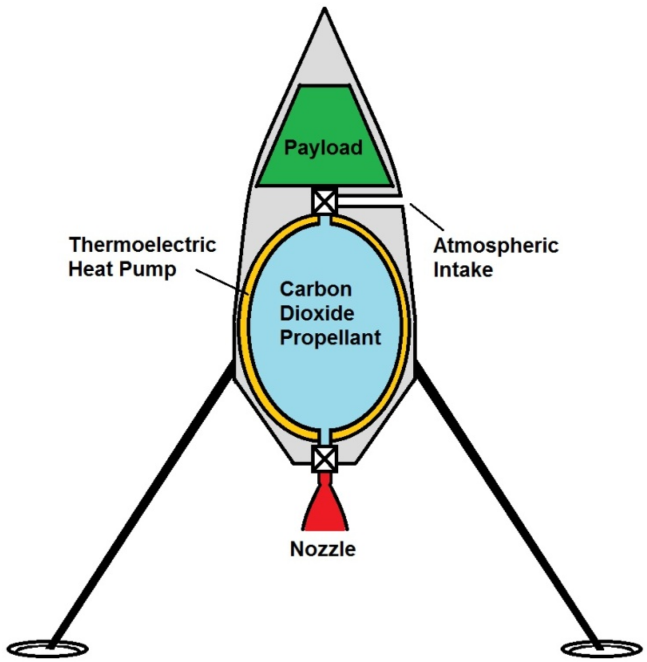
Thermoelectric Heat Pump



Surround the carbon dioxide container with reversible thermoelectric elements

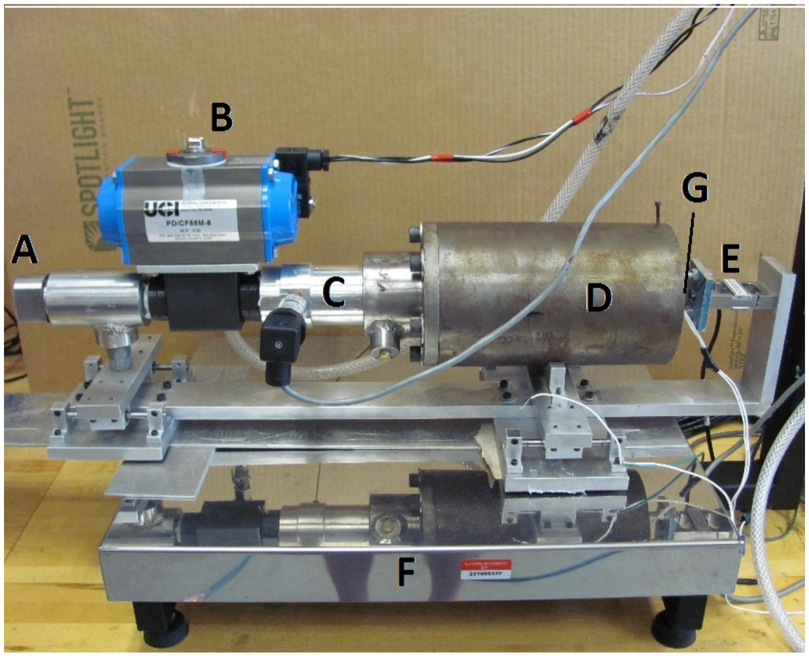
- Freeze dry ice (COP < 1)
- Heat the container (COP >1)

Blow-down Rocket

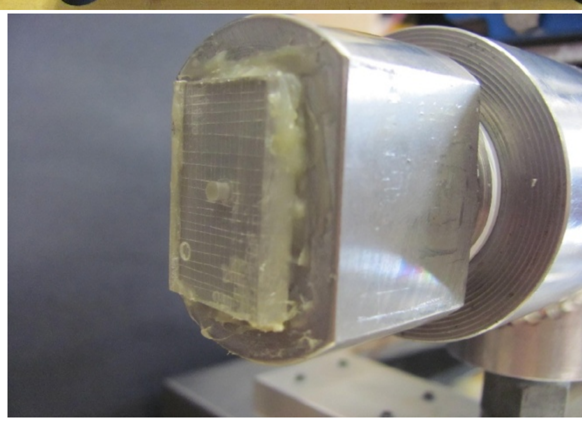


Objective: Measure the specific impulse of supercritical carbon dioxide when employed as a blow-down propellant.

Blow-down Experimental Apparatus

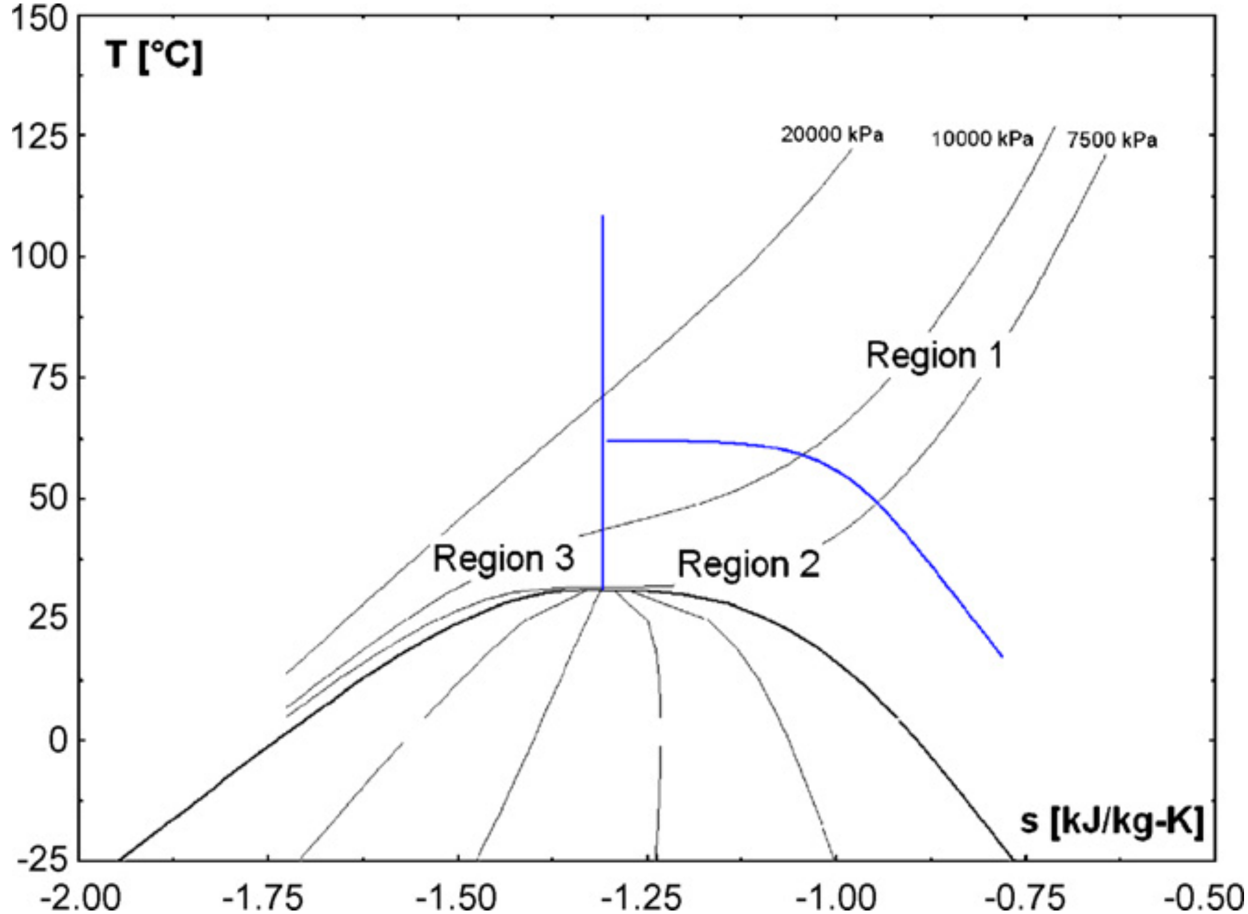


(A)Supersonic nozzle
(B) Pneumatic valve
(C) Pressure transducer
(D) Pressure vessel
(E) Thrust load cell
(F) Digital load platform
(G) Electric plug heater



2mm throat diameter, Mach 2 supersonic nozzle

Blow-down Behavior

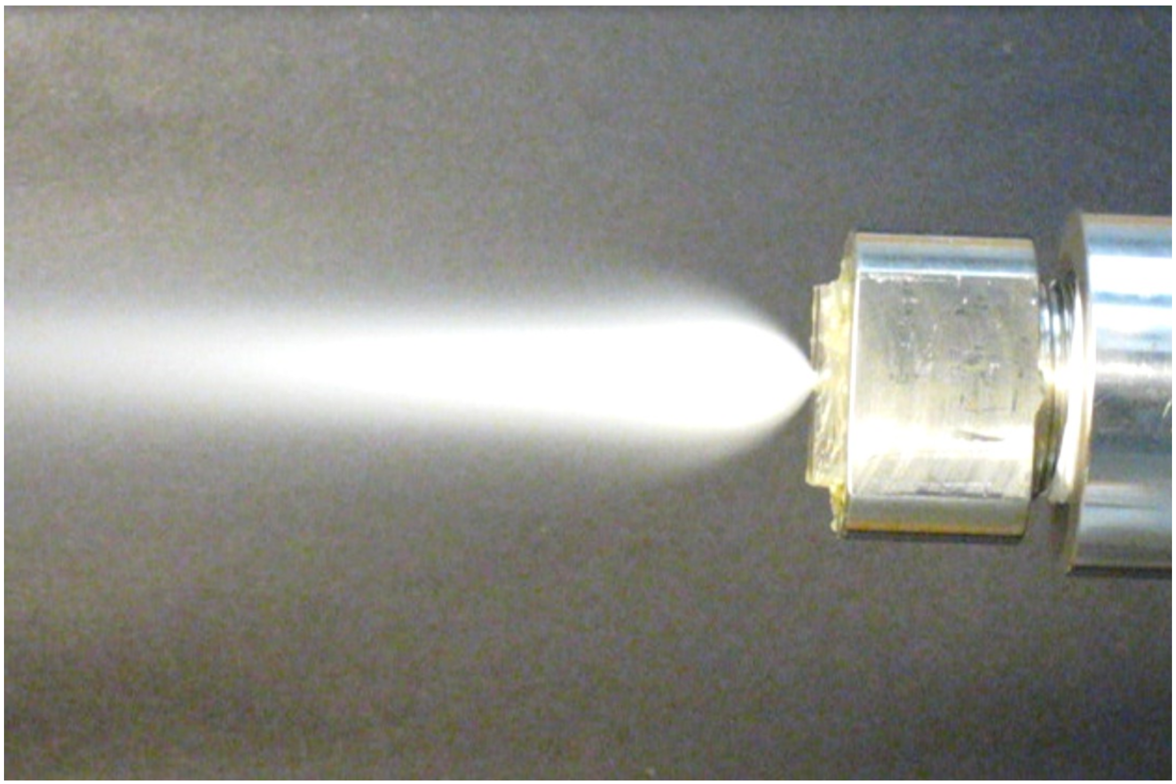


Region 1: Single phase superheated vapor
Region 2: Condensing two-phase mixture
Region 3: Vaporizing two-phase mixture

Testing Procedure

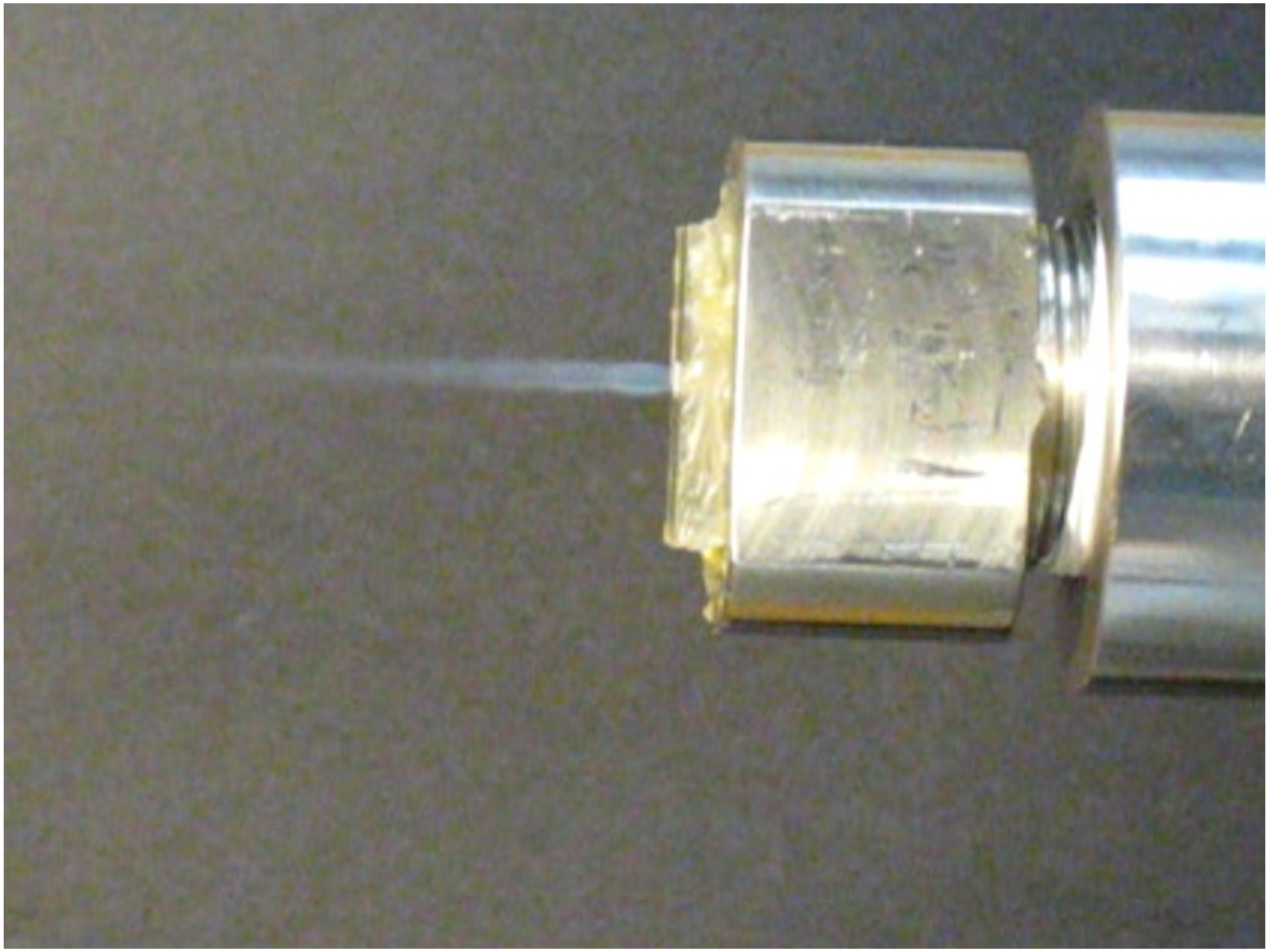
- The pressure vessel is charged with a specified mass of commercially available dry ice.
- When the pressure vessel is sealed an electric heater is used to heat and pressurize the CO_2.
- The pressure and temperature are monitored throughout the heating process until the desired initial conditions are reached.
- A pneumatic valve is actuated, establishing supersonic CO_2 flow.

Test Results



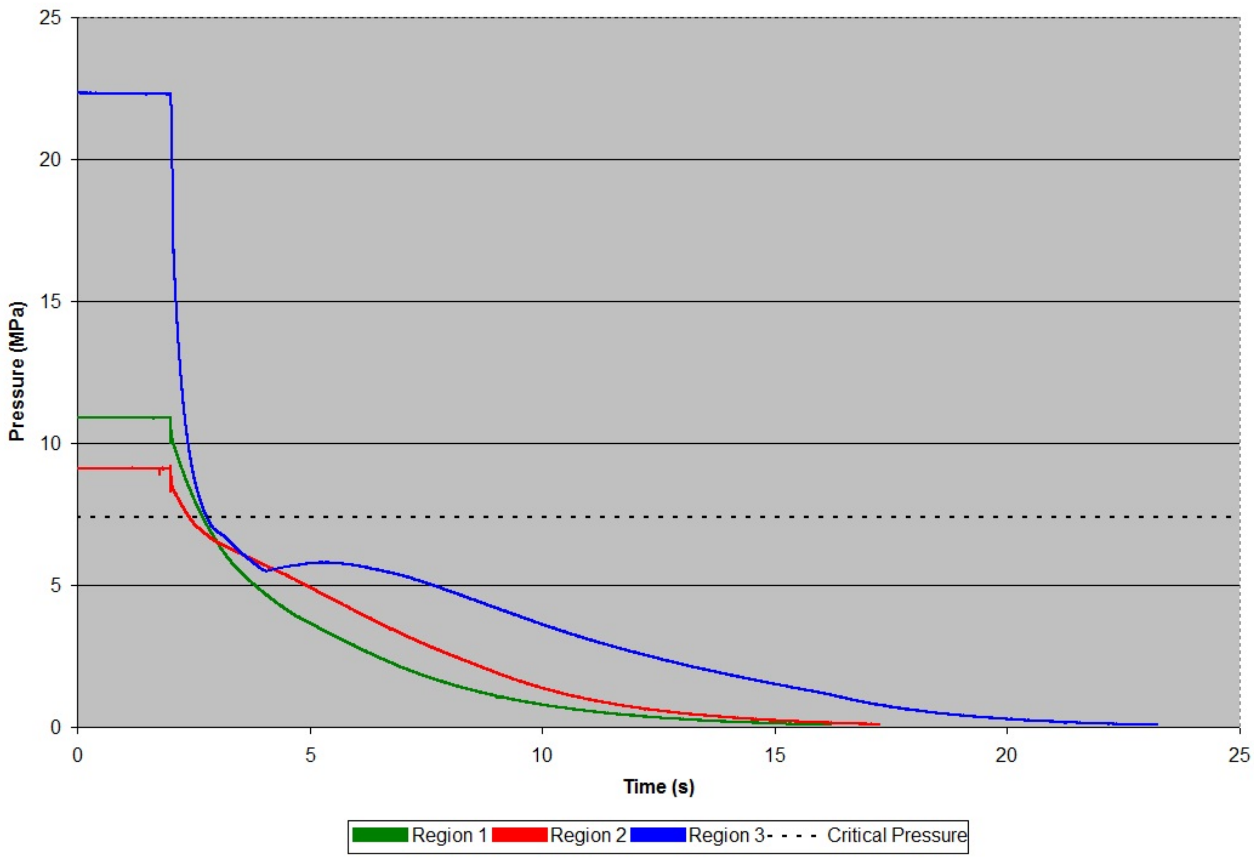
Images obtained during blow-down (Region 2)--condensing-fluid flow visualization.

Under-expanded jet, just after initiation of blow-down.



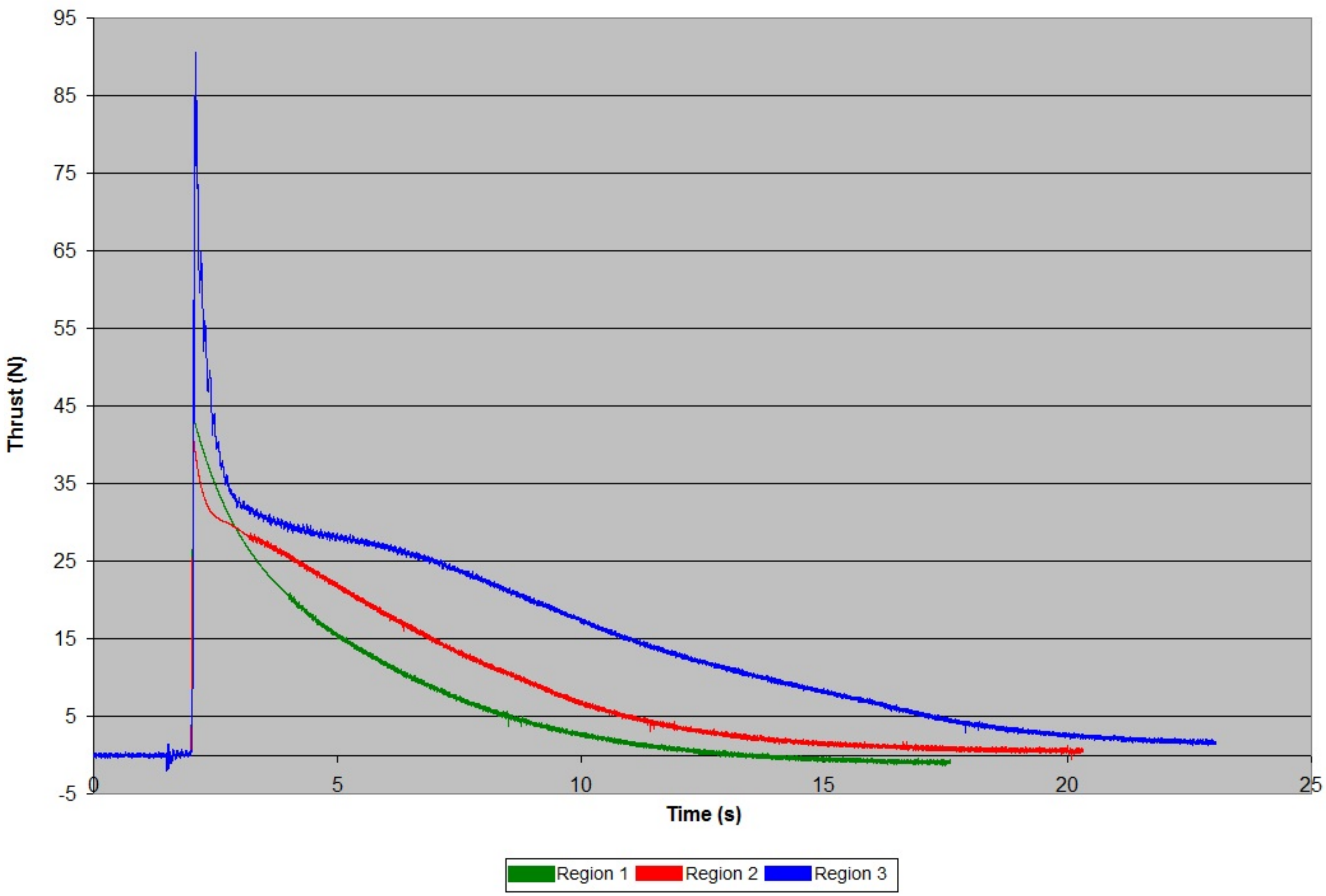
Classic over-expanded shock pattern—late-stage blow-down.

Pressure and Temperature



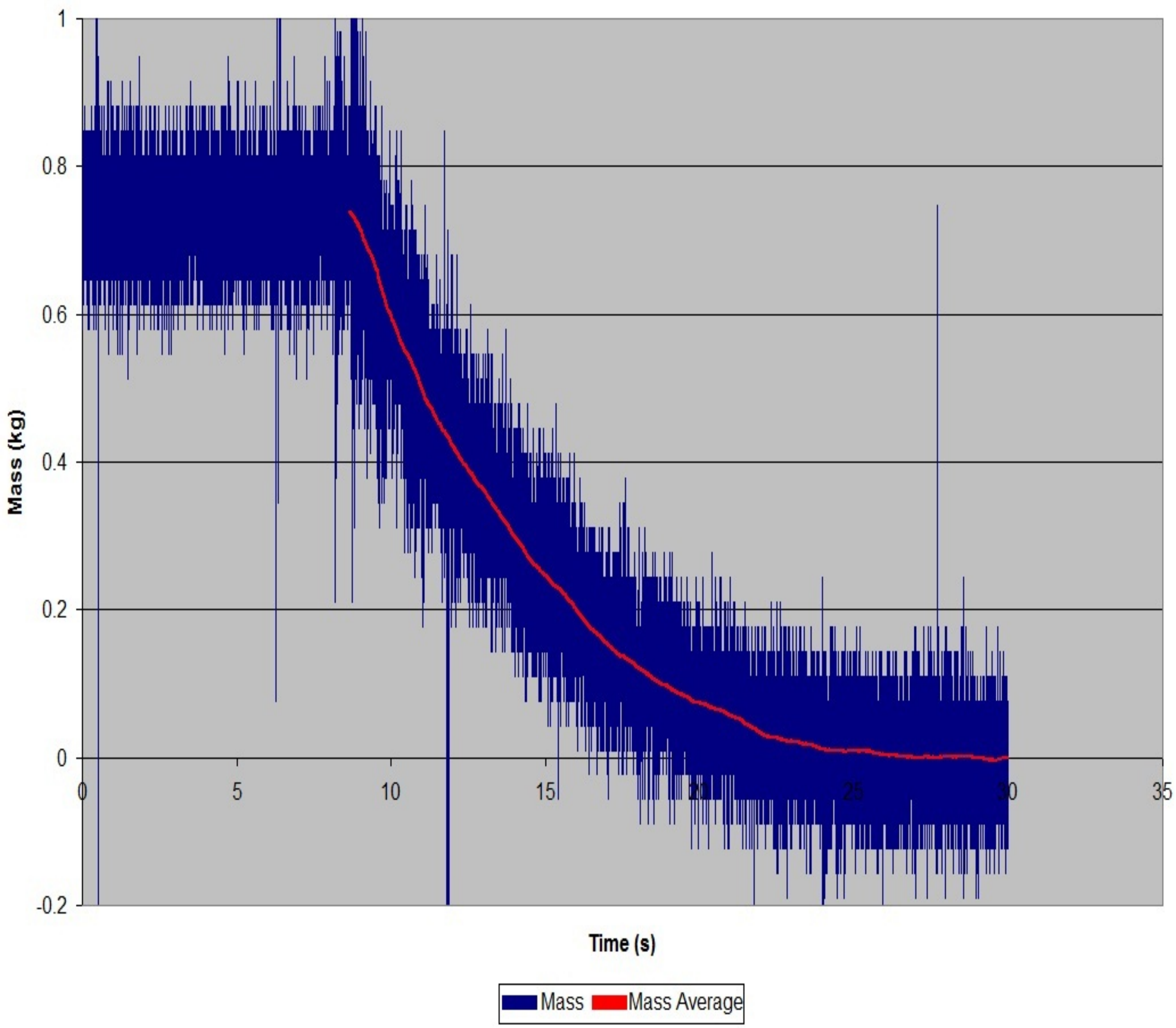
Slow thermocouple response produced unreliable pressure-tank thermodynamic data.

Thrust

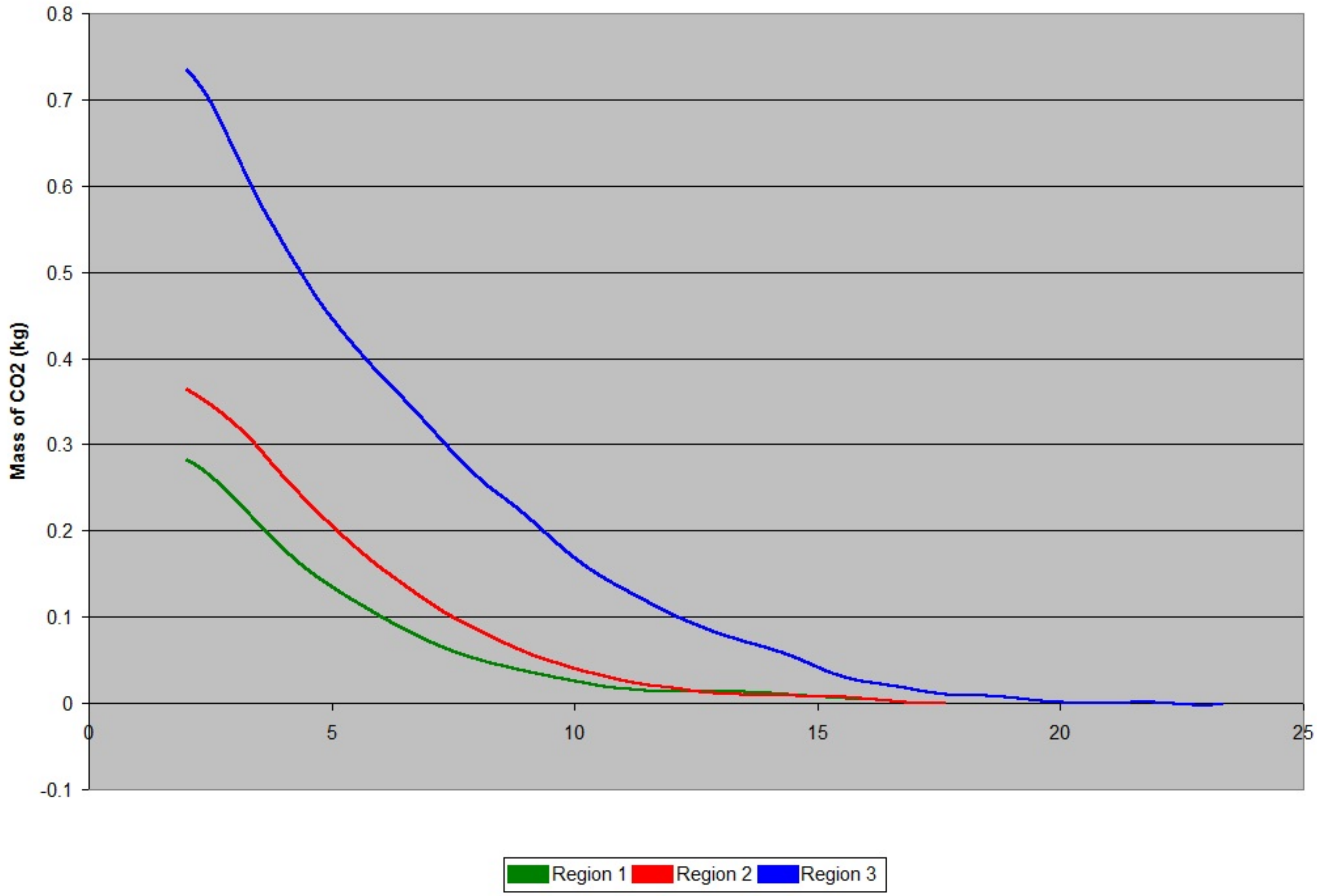


Thrust (N)
95
85
75
65
55
45
35
25
15
5
-5
0
5
10
15
20
25
Time (s)
Region 1
Region 2
Region 3

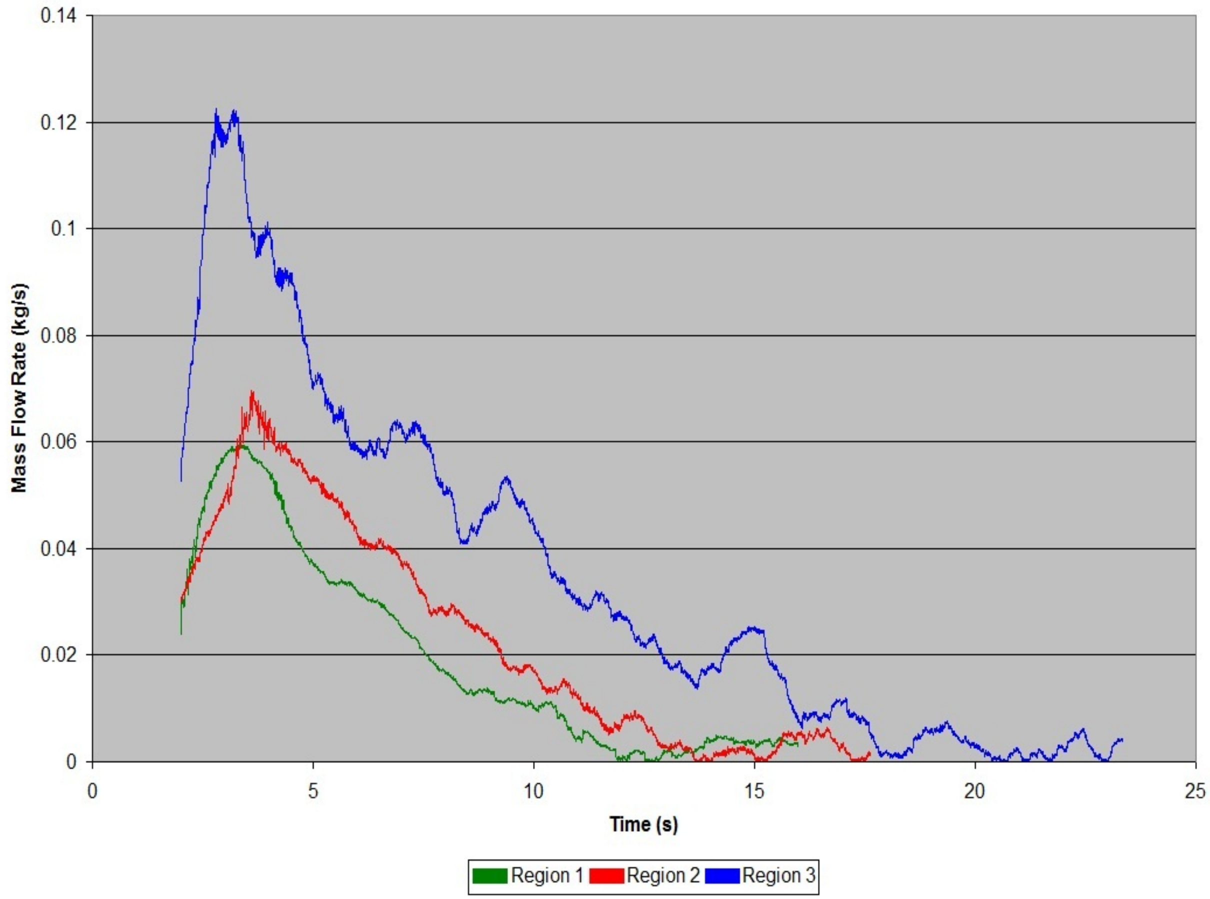
Propellant Mass vs. Time



Propellant Mass Histories

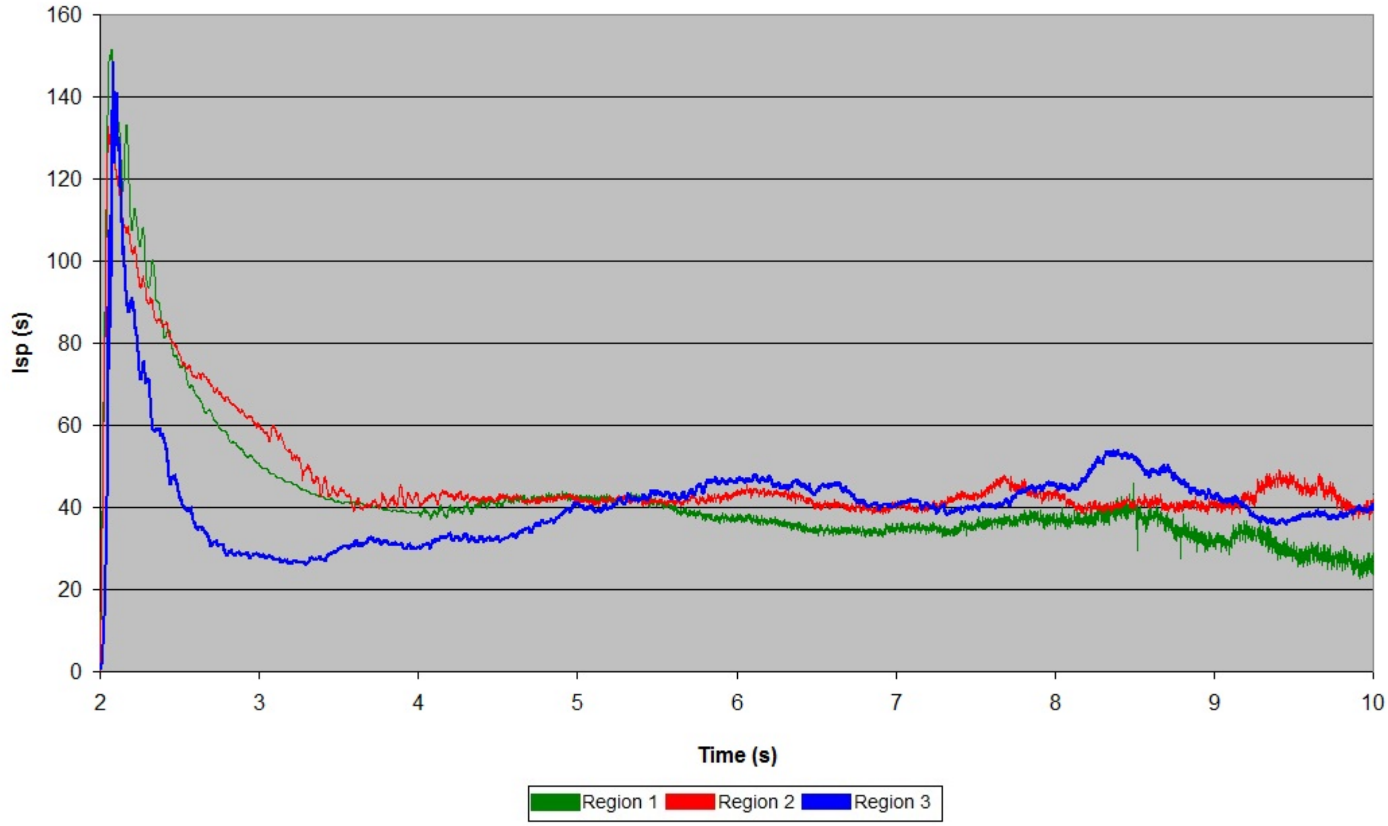


Mass Flow Rates



Due to start up transients, initial flow rates are suspect.

Specific Impulse Performance



Conclusions

By expanding supercritical CO_2 through a Mach 2 nozzle, 100 s specific impulse "spikes" are achievable.

Sustained specific impulse performance of about 40 s occurred in subcritical regime.

Overall performance of Region 1 was poor with low thrust levels that decreased more rapidly than blow-down from Regions 1 & 3.

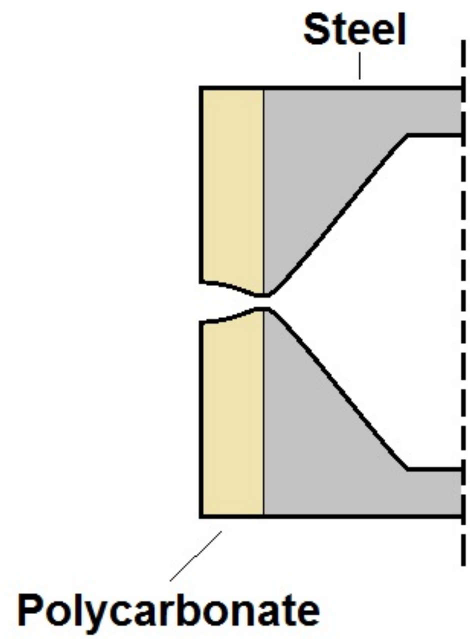
Region 3 had the highest, most sustained thrust levels, but with lower specific impulse performance in the initial supercritical regime.

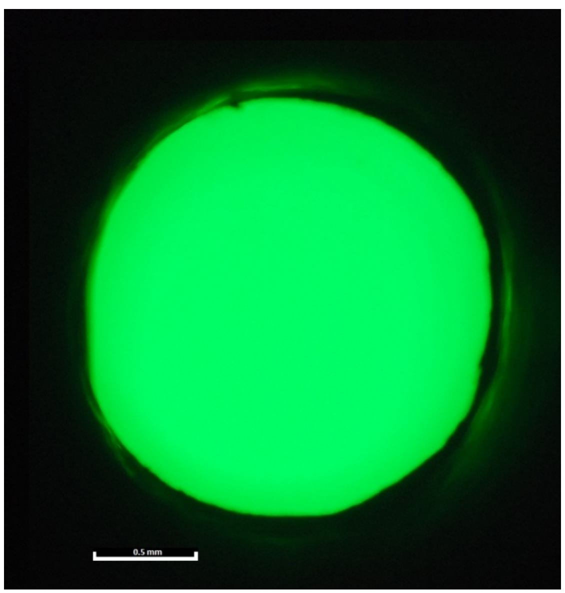
Region 2—condensing, two-phase flow—combined good specific impulse performance throughout with sustained moderate thrust levels. ***The lower initial pressure and temperature conditions associated with Region 2 can relax design requirements, enhancing potential supercritical CO_2 propulsion opportunities*.**


Questions?

Nozzle Construction

- ➢Composite nozzle construction.
- ➢Converging section is made of steel.
- ➢Diverging section is milled from polycarbonate.
- ➢Nozzle profile milled with a precision CNC machine.





The two section were aligned and joined with epoxy at the throat.